

15

Multiplication stage 160 allows the application of scale factors that adjust the relative gain of each code-channel for the purposes of power control. Multiplication stage 162 may be effected by a modulo-2 addition and allows the application of an orthogonal function (OF) (e.g., a Walsh or Hadamard code). Multiplication stage 164 applies various pseudo-noise (PN) codes on a unit chip interval basis to spread the code-channels in a well-known manner. Multiplication stage 164 may also be effected by a modulo-2 addition.

After stages 160, 162 and 164, the N code-channels are summed together on a unit interval by unit interval basis in an adding stage 166 to form composite signal stream 168. Those skilled in the art will appreciate that in this CDMA embodiment, the unit intervals discussed above are equivalent to chip intervals here. Moreover, in many of the unit chip intervals, the signals from many of the different code-channels will cancel each other out. Thus, composite signal stream 168 will have a modest average power level. However, in rare circumstances, unit chip intervals will occur in which the values for the N code-channels tend to add together with very little or no canceling. In these infrequent circumstances composite signal stream 168 will exhibit a peak level which far exceeds the average level. Consequently, composite signal stream 168 exhibits a high peak-to-average power ratio.

Composite signal stream 168 is routed to pulse-spreading filter 76 which operates at the unit chip interval rate. As with the above-discussed embodiment, pulse-spreading filter 76 is desirably implemented as a Nyquist-type filter because such filters approach near-ideal conditions by spreading pulse energy over many unit intervals to constrain the resulting modulated signal 74 to a predetermined bandwidth without unduly contributing to inter-chip or inter-symbol interference, but this is not a requirement. In this CDMA embodiment, composite signal stream 168, which already exhibits a high peak-to-average power ratio, is filtered in a manner which exacerbates the already high peak-to-average power ratio.

As discussed above, modulated signal 74 includes off-time and on-time signal streams 86 and 84 (FIG. 4) which are routed to off-time and on-time constrained-envelope generators 106 and optionally 106' to generate constrained error signals 108 as discussed above for combining with delayed modulated signal 140 to reduce the infrequent peaks without significantly increasing bandwidth. Constrained-envelope generators 106 operate at the unit chip interval rate. In this CDMA embodiment, any convenient threshold that achieves results in an altered modulated signal 112 easily amplified by substantially linear amplifier 146 without too severely increasing distortion may be generated by threshold generator 118.

Thus, in the CDMA embodiment modulated signal 74 exhibits a desired predetermined bandwidth due, at least in part, to the operation of pulse-spreading filter 76. As with the previous embodiment, modulated signal 74 exhibits an undesirably high peak-to-average power ratio. However, in the CDMA embodiment the undesirably high peak-to-average power ratio results from combining the numerous code-channels and from the operation of pulse-spreading filter 76. Regardless of the cause, peaks are identified in constrained envelope generators 106 and reduced by the application of error bursts 135 (FIG. 4) constructed in signal shape to exhibit substantially the same bandwidth as is exhibited by modulated signal 74, or a smaller bandwidth, and constructed in time and magnitude to diminish peaks to more acceptable levels.

The distortion discussed above in connection with FIG. 7 poses even less of a detriment in the CDMA embodiment. The noise induced by the infrequent peak-reduction error

16

bursts 135 is spread in a CDMA receiver circuit 30 (FIG. 1) so as to be distributed over the entire wide bandwidth shared by all code-channels. Consequently, for any single code-channel the noise of constrained-envelope error signals 108 remains well below the noise floor caused by all other code-channels.

In summary, the present invention provides an improved constrained-envelope transmitter and method therefor. A constrained-envelope generator is provided to generate a signal which, when combined with a modulated signal that exhibits a predetermined bandwidth, reduces peak-to-average power ratio without increasing the predetermined bandwidth. The modulated signal typically exhibits a desired bandwidth but undesirably large peak-to-average power ratio. However, it is adjusted to lessen the peak-to-average power ratio without increasing bandwidth. In one embodiment, a CDMA modulator provides a modulation signal that is a composite of many code-channels and exhibits an undesirably high peak-to-average power ratio. The composite modulation signal is adjusted so that the adjusted signal may be faithfully amplified by a relatively inexpensive power amplifier otherwise incapable of faithfully reproducing the undesirably high peak-to-average power ratio.

Although the preferred embodiments of the invention have been illustrated and described in detail, it will be readily apparent to those skilled in the art that various modifications may be made therein without departing from the spirit of the invention or from the scope of the appended claims. For example, the present invention may be adapted to many types of modulations. Moreover, while the above-discussed preferred embodiments discuss generating digital constrained-envelope error signals which are added to digital modulated signals, those skilled in the art can readily adapt the teaching of the present invention to analog signals. These and other changes and modifications are intended to be included in the scope of the claims.

What is claimed is:

1. A constrained-envelope digital communications transmitter circuit comprising:

a modulated-signal generator for generating a first modulated signal conveying to-be-communicated data, having a first bandwidth and having a first peak-to-average amplitude ratio;

a constrained-envelope generator for generating a constrained bandwidth error signal in response to said first modulated signal;

a combining circuit for combining said constrained bandwidth error signal with said first modulated signal to produce a second modulated signal conveying said to-be-communicated data, said second modulated signal having substantially said first bandwidth and a second peak-to-average amplitude ratio, said second peak-to-average amplitude ratio being less than said first peak-to-average amplitude ratio; and

a substantially linear amplifier configured to amplify said second modulated signal.

2. A constrained-envelope digital communications transmitter circuit as claimed in claim 1 additionally comprising a delay element coupled between said modulated-signal generator and said combining circuit to delay said first modulated signal into synchronism with said constrained bandwidth error signal.

3. A constrained-envelope digital communications transmitter circuit as claimed in claim 2, wherein said constrained-envelope generator is configured so that said constrained bandwidth error signal exhibits a bandwidth substantially equal to or less than said first bandwidth.

4. A constrained-envelope digital communications transmitter circuit as claimed in claim 2 wherein:

17

peaking unit intervals occur when said first modulated signal exhibits magnitudes greater than a threshold; said constrained bandwidth error signal includes error bursts for said peaking unit intervals, wherein each error burst spreads energy over a plurality of unit intervals and exhibits a peak in one unit interval; and said delay element delays said first modulated signal so that error burst peaks substantially temporally coincide with said peaking unit intervals.

5. A constrained-envelope digital communications transmitter circuit as claimed in claim 4 wherein said error burst peaks exhibit amplitudes which are responsive to amounts by which magnitudes of said first modulated signal exceed said threshold.

6. A constrained envelope digital communications transmitter circuit as claimed in claim 1 wherein said modulated-signal generator is a code division multiple access (CDMA) modulator and said first modulated signal conveys a plurality of code-channels of said to-be-communicated data.

7. A constrained-envelope digital communications transmitter circuit as claimed in claim 6 wherein said CDMA modulator includes a Nyquist-type pulse spreading filter which provides said first modulated signal.

8. A constrained-envelope digital communications transmitter circuit as claimed in claim 1 wherein said constrained-envelope generator comprises:

- a pulse generator responsive to said first modulated signal; and
- a filter having an input coupled to said pulse generator and being configured to generate said constrained bandwidth error signal.

9. A constrained-envelope digital communications transmitter circuit as claimed in claim 8 wherein said pulse generator is configured to generate a pulse when said first modulated signal exhibits a magnitude greater than a threshold.

10. A constrained-envelope digital communications transmitter circuit as claimed in claim 9 wherein said pulse generator is further configured so that said pulse exhibits an amplitude which is responsive to a value by which said first modulated signal exhibits said magnitude greater than said threshold.

11. A constrained-envelope digital communications transmitter circuit as claimed in claim 1 wherein said substantially linear amplifier comprises:

- a linearizer configured to pre-distort said second modulated signal into a pre-distorted signal; and
- a radio-frequency amplifying circuit configured to generate a radio-frequency broadcast signal from said pre-distorted signal.

12. In a digital communications system, a method for transmitting a constrained-envelope communications signal comprising:

- generating a first modulated signal conveying to-be-communicated data and having a first bandwidth and a first peak-to-average amplitude ratio;
- generating a constrained bandwidth error signal in response to said first modulated signal;
- combining said constrained bandwidth error signal with said first modulated signal to produce a second modulated signal conveying said to-be-communicated data, said second modulated signal having substantially said first bandwidth and a second peak-to-average amplitude ratio, said second peak-to-average amplitude ratio being less than said first peak-to-average amplitude ratio; and

linearly amplifying said second modulated signal.

13. A method as claimed in claim 12 wherein said constrained bandwidth error signal exhibits a bandwidth substantially equal to or less than said first bandwidth.

18

14. A method as claimed in claim 13 additionally comprising delaying said first modulated signal into synchronism with said constrained bandwidth error signal.

15. A method as claimed in claim 14 wherein:

- peaking unit intervals occur when said first modulated signal exhibits magnitudes greater than a threshold;
- said constrained bandwidth error signal includes error bursts for said peaking unit intervals, wherein each error burst spreads energy over a plurality of unit intervals and exhibits a peak in one unit interval; and
- said first modulated signal is delayed so that error burst peaks substantially temporally coincide with said peaking unit intervals.

16. A method as claimed in claim 15 additionally comprising forming said constrained bandwidth error signal so that said error burst peaks exhibit amplitudes which are responsive to amounts by which magnitudes of said first modulated signal exceed said threshold.

17. A method as claimed in claim 12 wherein said first-modulated-signal-generating activity configures said first modulated signal as a code division multiple access (CDMA) signal conveying a plurality of code-channels of said to-be-communicated data.

18. A constrained-envelope digital communications transmitter circuit comprising:

- a modulated-signal generator for generating a first modulated signal conveying to-be-communicated data, having a first bandwidth and having a first peak-to-average amplitude ratio;
- a constrained-envelope generator for generating a constrained bandwidth error signal in response to said first modulated signal, said constrained bandwidth error signal exhibiting a bandwidth substantially equal to or less than said first bandwidth, and said constrained bandwidth error signal exhibiting peak amplitudes which are responsive to amounts by which magnitudes of said first modulated signal exceed a threshold;
- a delay element for delaying said first modulated signal into synchronism with said constrained bandwidth error signal;
- a combining circuit for combining said constrained bandwidth error signal with said first modulated signal to produce a second modulated signal conveying said to-be-communicated data, said second modulated signal having substantially said first bandwidth and a second peak-to-average amplitude ratio, said second peak-to-average amplitude ratio being less than said first peak-to-average amplitude ratio; and
- a substantially linear amplifier configured to amplify said second modulated signal.

19. A constrained-envelope digital communications transmitter circuit as claimed in claim 18 wherein said modulated-signal generator is a code division multiple access (CDMA) modulator and said first modulated signal conveys a plurality of code-channels of said to-be-communicated data.

20. A constrained-envelope digital communications transmitter circuit as claimed in claim 18 wherein:

- peaking unit intervals occur when said first modulated signal exhibits magnitudes greater than said threshold;
- said constrained bandwidth error signal includes error bursts for said peaking unit intervals, wherein each error burst spreads energy over a plurality of unit intervals and exhibits a peak in one unit interval; and
- said delay element delays said first modulated signal so that error burst peaks substantially temporally coincide with said peaking unit intervals.

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